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ABSTRACT

This unit explores a recent and controversial theory of the origin of much of the Earth's natural gas and oil. The materials provided will give students the opportunity to: (1) gain an understanding of science and what is involved in the acceptance or rejection of theories; (2) learn about fossil fuels, especially natural gas; (3) learn the traditional and abiogenic theories of natural gas formation; (4) evaluate the merits of the two theories; and (5) evaluate the knowledge gained about natural gas and its origin. Included in the unit are an introduction, with objectives; an outline and notes to the teacher; an activity on the controversy of science; a fossil fuel and natural gas fact sheet and activities; an article on theories and questions for discussion and review; a viewing guide and discussion questions to use with a related videotape; a critical thinking activity for debate or role play; a quiz; and an evaluative worksheet. An appendix on the supply of natural gas, a list of additional available materials, and a glossary complete the unit. (RT)

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Theories and Conflict: The Origins of Natural Gas

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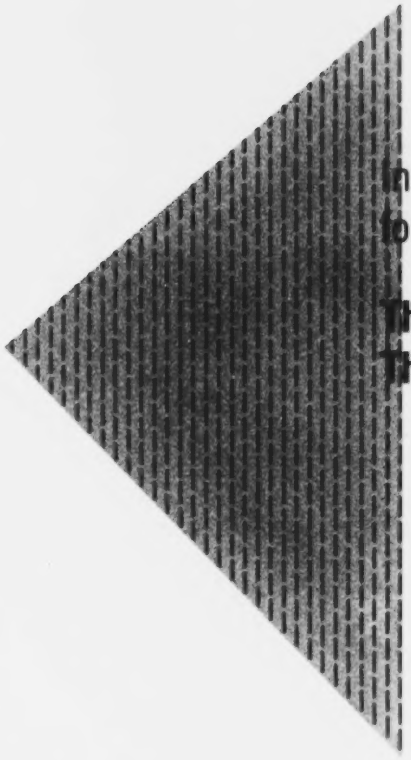

Instructional Materials
for

Theories and Conflict: The Origins of Natural Gas

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1. Introduction

Instructional Objectives

This unit explores a recent and controversial theory of the origin of much of the Earth's natural gas and oil. It also gives students information on the traditional theory of petroleum formation. The materials provided here will give students in grades 8-12 the opportunity to:

1. Gain an understanding of how science is "done," and what, in addition to the facts, is involved in the acceptance or rejection of theories.
2. Learn important facts about fossil fuels in general and natural gas in particular.
3. Learn the traditional theory of natural gas formation.
4. Learn the abiogenic theory of natural gas formation.
5. Evaluate the merits of the two theories.
6. Evaluate the knowledge gained about natural gas and its origin at the conclusion of the unit.

Unit Outline

The unit includes the following elements:

1. Introductory activity.
2. Fossil fuel and natural gas fact sheet and activities.
3. Article on the biological and abiogenic theories of natural gas formation, and questions for discussion and review; answers to those questions.
4. Videotape—"Theories and Conflict: The Origin of Natural Gas" (may not be available everywhere).
5. Viewing guide and discussion questions for "Theories and Conflict: The Origin of Natural Gas;" answers to the questions.
6. Critical thinking activity (role play/debate).
7. Worksheet/quiz.
8. Evaluative worksheet.
9. Sources for further information.
10. Appendix on the supply of natural gas.
11. Evaluation form.
12. Glossary.

Notes To The Teacher

This unit is written for students in grades 8-12. It could be used in general science, earth science, biology, debate, current events, social studies, science-technology-society, or reading classes. It could also be adapted for adult audiences, advanced high school or junior college students, or gifted younger students.

If the entire unit is presented as written, it could be completed in four class periods (45-60 minutes each) using the following schedule:

Day 1: Introductory Activity
Fossil Fuel Facts Activity
Homework: Find out all you can about natural gas.

Day 2: Natural Gas Activity
Begin reading article together.
Homework: Finish article and complete "Questions for Review."

Day 3: Discuss "Questions for Discussion."
See and discuss videotape.

Day 4: Role-play Activity
Homework: Unit Worksheet

The unit could be shortened by simply presenting the facts about fossil fuels and natural gas to the students. It could be lengthened by having students do additional research and by examining at length the way in which scientific theories develop.

This material may be used alone, but it is designed to accompany a videotape that is either available for loan from many local gas companies or for purchase from the American Gas Association, 1515 Wilson Blvd., Arlington, VA 22209. An order form for the videotape is included with these materials.

Pages that will need to be copied for classroom use are marked with a blue triangle in the lower corner.

2. Introductory Activity—Science As Controversy

This activity may be used to generate a discussion of the controversial nature of science.

- Ask students to think of times in the past or present when scientists disagreed. List these scientific controversies on the board. (Some examples: Flat/spherical Earth; Plate tectonics; Sun/Earth at center of solar system; Spontaneous generation/biogenesis; Germ Theory; Evolution/creationism.)
- Pose the following questions:

1. If scientific research discovers the "facts," then how can there be disagreement among scientists?
2. When there is disagreement, how do you think it is finally resolved?
3. How do you think each of the following factors could influence the development or acceptance of any theory? Give specific examples whenever possible.
   —economic trends
   —prevailing social attitudes
   —personalities of scientists involved
   —outcome ("good news" theories *vs* "bad news" theories)
   —personal interest and gain

- When the discussion is over, explain to the students that they will be looking at a scientific controversy going on right now that may well have a significant impact on the kind of energy they will use in the future; before getting into the controversy, though, they need to know some factual information.

NOTE: There are several excellent sources on this subject for your own reading:

Caws, Peter. "Quest and test—Seeing the world with a scientist's eye." *The Christian Science Monitor.* April 22, 1988, p. 88.

Kuhn, Thomas. *The Structure of Scientific Revolutions,* 2nd ed. Chicago: University of Chicago Press, 1970.

Lerner, Lawrence S., and Bennetta, William J. "The Treatment of Theory in Textbooks." *The Science Teacher.* April, 1988, pp. 37-41.

3. Fact Sheet—Fossil Fuels In General, Natural Gas In Particular

These facts represent information with which students should be familiar before discussing the traditional and abiogenic theories of the origin of petroleum. Suggestions for teaching activities follow.

General Facts About Fossil Fuels:

- Coal, oil, and natural gas are known as fossil fuels.
- They consist of a mixture of compounds made mostly of the elements carbon and hydrogen (hydrocarbons).
- They are burned to provide energy for heating, generating electricity, running engines, etc.
- They are used to make plastics, synthetic fabrics, fertilizer, pesticides, shampoo, and many other commonly-used materials.
- They are found in underground reserves, sometimes located under bodies of water.
- Their name, "fossil fuels," comes from the theory that they have arisen from the remains of plants and microscopic animals that were buried under sediments millions of years ago.
- They provide for about 91% of the energy needs in the United States.

Facts About Natural Gas:

- It is an odorless gas (a chemical is added to give it an odor so that leaks can be detected); it is lighter than air.
- It is often found with oil or coal; used to be burned off from oil wells because it was not thought to be useful or economically worthwhile.

- It consists mostly of the simple hydrocarbon *methane* (CH_4).
- It is transported primarily by a network of pipelines.
- It is the cleanest-burning fossil fuel, since its combustion produces only carbon dioxide and water vapor.
- It is measured in cubic feet or cubic meters.
- It is used for cooking, clothes-drying, and heating homes and water; heating businesses; fueling industries; generating electricity; running cars and buses; manufacturing plastics, synthetic fabrics, and other synthetic materials.
- It often requires little refining before being used.
- It provides for about 24-26% of the energy needs in the United States.

Suggested Teaching Activities

1. **Facts about Fossil Fuels:** Because students may already know quite a bit about fossil fuels, you can capitalize on this by holding a brainstorming session.

- Write **Fossil Fuels** in the center of the blackboard.
- Give students about two minutes to jot down individually everything they know or have heard about fossil fuels, including properties, uses, recovery, etc.
- When the time is up, explain the one important brainstorming rule: Every piece of information contributed is accepted and written on the board, with no discussion. Information will be corrected or deleted once the brainstorming is over.
- Brainstorm until students no longer have ideas to contribute. (If you are familiar with "cognitive mapping," it might be a useful way to record student ideas.)
- Go over the information contributed and correct or delete with the students any erroneous or incomplete items. Add facts that do not appear on the class list.
- You may want to have students copy the final list into their notes for future reference.

2. **Facts about Natural Gas:** In this area, student knowledge may be more spotty. You may want to have students research these facts for themselves. One way in which this might be done is to divide the class into groups and give each group a question about natural gas to answer from books in the school library. A list of possible questions (corresponding to facts on the list) appears below:

- What is the chemical nature of natural gas (major components, physical properties)? (ANSWER: It is a colorless, odorless gas made mostly of methane, CH_4.)
- How does natural gas compare to coal and oil in terms of cleanliness when burned? (ANSWER: It is cleaner than both, producing only water vapor and carbon dioxide when burned.)
- What are the most common uses of natural gas? (ANSWER: Heating homes and water, cooking, clothes drying, industry.)
- Where is natural gas commonly found? (ANSWER: In underground reservoirs.)
- How is natural gas transported? (ANSWER: Usually by pipeline.)
- What is the odorant added to natural gas for safety purposes? (ANSWER: Mercaptan is added to give it an odor so that leaks can be detected.)
- In what units is natural gas measured? (ANSWER: In cubic feet or cubic meters.)

The groups can present their findings to the class.

This activity could also be organized as a game, by dividing the class into two teams and giving each team the responsibility of learning as much as possible about natural gas in a specified period of time. It might be helpful to stress that each member of the team should be up to speed on the subject because anyone on the team may be asked any question; alternatively, different members of the team could be given different "areas of expertise." The game could be run on a quiz-show format, with prizes or points awarded for correct responses.

3. A petroleum geologist or gas company speaker could be invited to the classroom to give a presentation on oil and gas.

4. Contact your local gas company to see if they have available any films on natural gas exploration and recovery.

4. What is the Origin of Natural Gas and Oil?

Introduction

In the first century B.C., the Roman poet Virgil gave a "recipe" for bees:

1. Kill a bull in the springtime.
2. Build a shed and put the dead bull on branches inside it.
3. Wait for summer, when the decaying body of the bull will produce bees.

This recipe was easily accepted by other Romans of the day; in fact, it was no surprise hundreds of years later when Flemish scientist Jean-Baptiste van Helmont proved that mice arose from sweaty shirts sprinkled with wheat. Others of that time believed that lice came from sweat, frogs from mud, and flies from meat. Francesco Redi, an Italian physician who lived in the mid-1600 s, tried to prove that this last example was not true by experimenting with meat in gauze-covered jars. While he did convince many people that the flies come *to* the meat and not from it, the question of spontaneous generation (living things coming from non-living things) was still unsettled for frogs and mice.

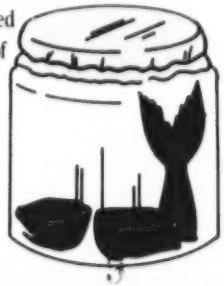
The issue became more complicated when the development of the microscope showed the existence of very tiny living organisms. John Needham, an eighteenth century English scientist, believed that microorganisms could spontaneously arise in broth, and he performed experiments to prove it. Several years later an Italian priest and biologist, Lazzarro Spallanzani, experimented to disprove Needham's theory; while some scientists accepted Spallanzani's work, many did not and continued to believe in spontaneous generation. It remained an open question until 1894, when the French doctor Louis Pasteur finally proved without a doubt that even the tiniest organisms come only from other tiny organisms, and not from broth alone.

You may be wondering if some of these people just weren't very smart. Some were probably brighter than others, but all were highly regarded scientists. Although some of their ideas may seem silly to us now, they were definitely not considered silly then; in fact, their ideas were very much in line with the beliefs of the day. And all of them made important contributions to science, by causing others to experiment further.*

There are similar examples in the more recent past. Twenty years ago "plate tectonics," the theory that the Earth's continents are and have been moving for millions of years, was considered ridiculous. After all, how could whole continents move? But today we have much evidence to show that this is indeed what has happened, and plate tectonics is widely accepted among geologists.

Controversies like these help us to expand our scientific knowledge, because they force scientists to do more and more research. The more heatedly scientists discuss an issue, the more certain you can be of a solid answer once everyone agrees.

You can probably think of other ideas in science about which scientists disagree. Today, one hotly disputed question concerns the origin of natural gas and oil. Though the debate has not received a great deal of attention in the media, the final answer may well determine the energy use patterns for heating, transportation, and industry throughout the world in the years to come. In the following pages, you will learn about two competing theories concerning the origin of natural gas and oil.



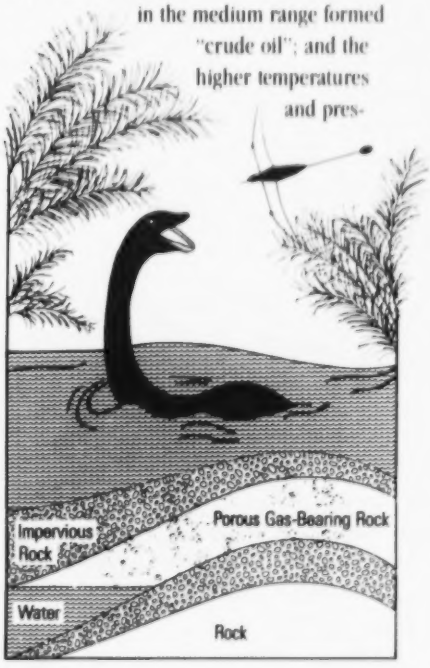
*It is interesting that the scientific community has come "full circle" on the question of spontaneous generation. More and more experiments now show how some of the complex molecular building blocks of life can spontaneously generate in laboratory conditions that mimic the conditions of the early Earth.

Part I: The Biological Theory of Natural Gas Formation

Most scientists believe that natural gas and oil originated millions of years ago, with the first stirrings of life in ancient seas and oceans. A multitude of creatures evolved, feeding upon plants and each other. As these tiny **aquatic** plants and animals died, they drifted downward in an almost ceaseless shower with other sediments, accumulating layer after layer upon the ocean floor.

Over eons of time, as the Earth's surface shifted and folded, the sediments were buried by layers of rock, entombing countless remains of plant and animal life. Heat and pressure transformed the sediments into sedimentary rock—shale and limestone. The overlying tons of rock eventually transformed the **organic** remains in the sediments into a tar-like substance called **kerogen**.

Continued high pressures and temperatures changed the kerogen into different forms of petroleum: the lower temperatures and pressures formed an asphalt-like material; those in the medium range formed "crude oil"; and the higher temperatures and pressures caused methane, the main component of natural gas, to form.



This pressure also changed the sediments into rock. This sedimentary rock, which contains bubbles of oil, gas, and water, is called "source rock," because in it was the source of the gas and oil. Shale and limestone are the most common source rocks.

As the oil and gas are formed in the source rocks, they are pushed out into nearby rocks that are more **porous** and can trap them. These porous rocks, called "reservoir rocks", are often sandstones and limestones. The petroleum is usually trapped in these rocks by overlying **nonporous** rocks (called "cap rocks") or water. If it isn't trapped, the gas or oil seeps to the surface and may break down in the air. When petroleum geologists prospect for oil and gas, they look for areas that have these three kinds of rock: source rocks that might contain petroleum, reservoir rocks that could store it, and cap rocks that would keep it from escaping.

To find these areas, geologists often collect **seismic** data. This is information that they gather by setting off explosions or mechanically generating sound-like waves at different depths in the ground and recording how the resulting shock waves bounce back. When charted, the shock waves indicate the locations of porous and dense areas, and of underground rock formations. They can use this information along with data gathered about the kinds of sediments in the area to make decisions on where to prospect.

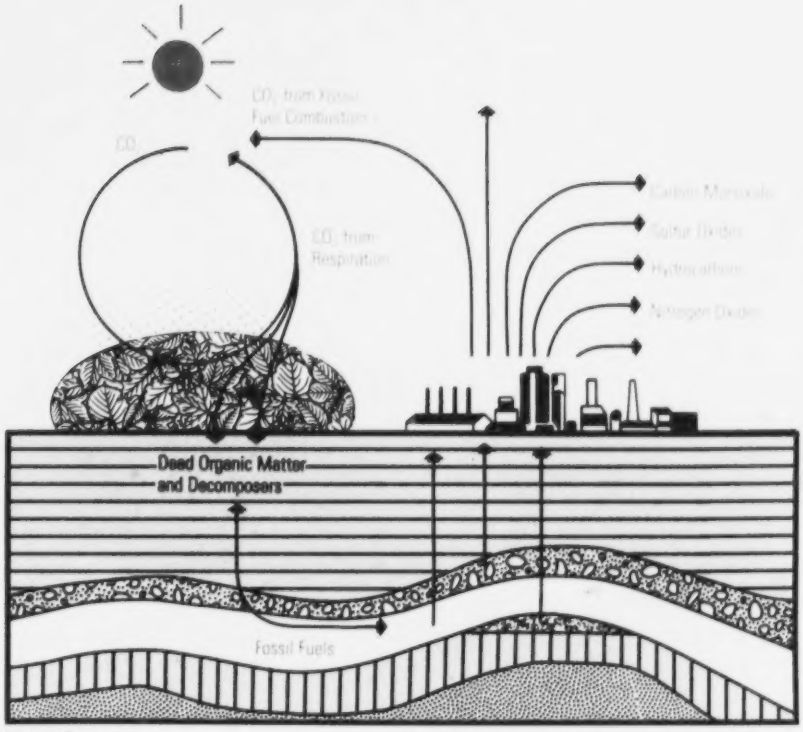
Though the processes described above are, according to most petroleum geologists, the only way that oil is created, they are not the only way to create natural gas. Some bacteria give off methane when they break down organic material. These bacteria are present in large quantities in garbage dumps, where they feed on banana peels, coffee grounds, paper, and other organic wastes. At some landfills the methane being produced is collected and sold to natural gas companies. Other projects tap the methane produced by the breakdown of sewage at sewage treatment plants, or the decay of cow manure and chicken feces. Scientists are also experimenting with decaying kelp (seaweed) and water hyacinths as a means to produce methane.

According to the biological theory, all of this natural gas (and oil) comes from living things: either the burial of those that lived long ago, or the breakdown by bacteria of dead plants and animals and their wastes today. The carbon that eventually became methane (CH_4) was originally carbon dioxide (CO_2), a compound in the atmosphere that plants use in photosynthesis to make sugars, oxygen, and new plant material. The carbon cycle below shows these processes:

There is much evidence to show that our gas and oil come solely from living things. First, many of the substances that make up natural gas and oil are substances that generally come only from plants and animals (though in the past few years these substances have been found on meteorites or created artificially in laboratories).

Second, oil and gas are **always** found near a source rock that has been under high temperatures and pressures; they are never found near source rocks that haven't been under high pressures (for example, rocks that contained organic matter but were never buried by other layers of rock). These findings indicate that high pressures and temperatures acting on source rocks produce gas and oil.

Third, petroleum from any given area has what is called a "signature," a unique mixture of the substances (oil, methane, carbon dioxide, trace elements, etc.) that make it up. For example, oil and gas from a well in Texas will have a signature different from oil and gas



Carbon Cycle

from a well in Alaska; it will not even be the same as oil from another field in Texas. If source rocks from a certain area are pressure-cooked, the result is oil and gas with the same exact signature as that of the gas and oil found in the reservoirs near that source rock. Therefore, the oil and gas must have come from the kerogen in the source rock.

If it is true that our oil and gas come mostly from plants and animals that were buried and "cooked" millions of years ago, then our reserves of these fuels are limited by the amounts of them. Each year statistics are given for proved reserves of natural gas—that is, reserves that we have already drilled for and found. (See the Appendix, Section IX, for further information on natural gas reserves.)

In addition to proved reserves, there are potential reserves—those that are thought to be there. Figures are given for probable, possible, and speculative amounts; each of these is based upon a great deal of research. Expanding these potential reserves still further are "nonconventional" sources of natural gas, such as gas found in geologic formations like Devonian shales in the Appalachian Mountains, concrete-like sands called "tight sands," coal seams, and geo-pressurized zones of methane-rich saltwater beneath the Gulf Coast. Gas can also be made from coal in a process called "coal gasification."

No matter how much natural gas we have left, the fact that our supply is not unlimited means that we will continue to rely to some degree upon other energy sources—coal, oil, nuclear power, hydro-electric dams, and solar, wind, and geothermal power—for some of our energy needs. While a few of these sources are quite promising, all have some economic or environmental problems. For example, an increased reliance on coal could add to the sulfur oxides in the air; nuclear power poses financial and environmental risks. Hydro-electric, wind, solar, and geothermal power, the "renewables," are clean, but are not available everywhere at a reasonable cost.

So, while we certainly have enough natural gas to last many years into the future, if we could find vast, as yet undiscovered reserves of natural gas in the Earth, our energy supplies would be increased, and problems associated with other energy forms reduced. A petroleum geologist's fantasy? Maybe—and maybe not. There is at least one man who thinks that we may indeed have additional huge reserves of natural gas, in places we have never even thought to look.

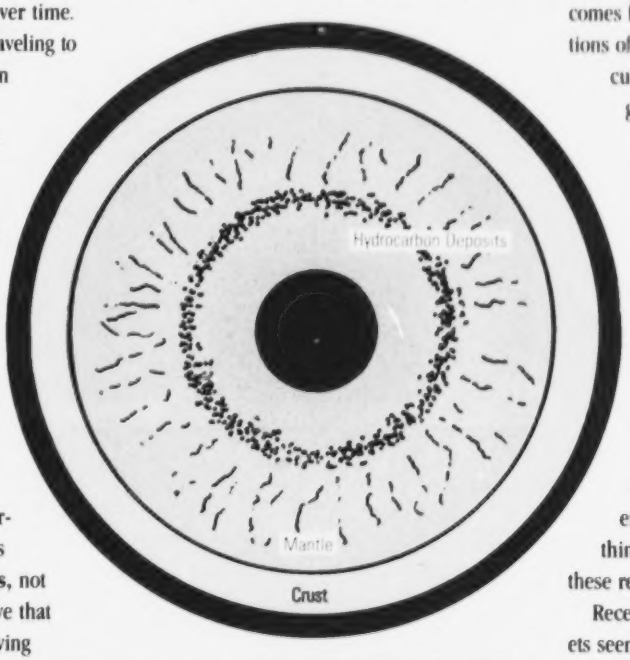
***Words in bold type are defined in the glossary.**

Part II: The Abiogenic Theory
(Condensed from an article by David Osborne, *The Atlantic,* February 1986.)

Thomas Gold is an **astrophysicist,** for many years the director of Cornell University's Center for Radiophysics and Space Research. He has worked in many fields, and has a reputation for coming up with ideas that are out of the mainstream. He made predictions about **pulsars** that were at first ignored, but later became widely accepted. He proved that the Earth's magnetic poles change over time. He insisted that the US astronauts traveling to the moon would land on dust, not on rocks, as almost everyone else believed—and he was right! He was also one of the originators of the **"steady-state" theory** of the universe, one that is no longer in favor.

Today Gold is challenging the biological theory of the origin of natural gas and oil. Gold had, for many years, been uncomfortable with the idea that all of the carbon on Earth had first existed as carbon dioxide, and became methane only after being incorporated into plants through photosynthesis. After all, carbon has been found on other planets mostly in the form of **hydrocarbons,** not carbon dioxide, but we do not believe that these planets have ever supported living things. Hydrocarbons are also found on certain meteorites, called **carbonaceous chondrites**. Gold hypothesizes that it was these meteorites crashing into the forming Earth that brought us much of our carbon. As this carbonaceous material is heated deep within the Earth, it would release methane and other hydrocarbons. Pressure would eventually push them up through cracks in the Earth's crust to the surface.

Gold's theory has met with much skepticism among many respected petroleum geologists. One has been quoted as saying that his idea is "on about the same level . . . as saying sugar-plum fairies will cure cancer." For many this theory, developed by someone who is not even a petroleum geologist, threatens all that they have been taught and have practiced—very successfully—for many years. Others welcome the idea that our natural gas reserves might be even greater than we had imagined, but do not believe that Gold understands petroleum geology in enough depth to develop a credible theory. But Gold's past experiences have taught him not to let the opinions of other scientists prevent him from following up on his own hunches.



For Gold, the existence of hydrocarbons on meteorites and on other planets is just one indicator of a non-biological, or **"abiogenic,"** origin for at least some of our gas and oil. Convincing, too, is the fact that many oil and gas reservoirs are found near the Earth's **fault** zones. Gold believes that these areas, because of their deep cracks, provide a cool path for abiogenic hydrocarbons from the Earth's **mantle** to escape. When these hydrocarbons come to the Earth's surface through hotter routes like volcanoes, they are burned up and become carbon dioxide. Proponents of the traditional theory hold that this carbon dioxide was always carbon dioxide; it cannot become methane until it has been incorporated into plants (and then, possibly animals) and decays.

Other evidence for Gold's abiogenic theory comes from the existence of high concentrations of "trace elements" like helium, mercury, vanadium, and nitrogen in natural gas. Gold believes that these elements could easily be "picked up" by methane as it migrates up from the mantle; traditional petroleum geologists think that oil and gas reservoirs are simply good traps for these elements. Supporting Gold is the fact that the amounts of these **trace elements** show a consistent pattern in different reservoirs found in the same large area; there would be no reason, Gold feels, for these elements to seep into a number of different reservoirs in exactly the same ratios. He thinks that it is more likely that all of these reservoirs have the same deep source.

Recent evidence accumulated by the Soviets seems to confirm one part of Gold's theory. Scientists in the USSR have been drilling the world's deepest hole in a granite shield north of the Arctic Circle. According to traditional geology, they should find no porous regions more than two or three miles deep, because the weight of the overlying rock would be so great as to make all rock at these depths very dense. Much to everyone's surprise, they have actually found very porous zones in areas as deep as ten miles into the Earth's crust. In these porous areas liquids and gases, including methane, circulate. Several years before these findings had occurred, Gold had hypothesized that such porous areas would exist due to the tremendous pressure

of the hydrocarbons pushing up from the Earth's mantle. These substances, he believed, would be pressurized enough to fracture the rock.

A recent drilling project in Sweden has provided some answers for the advocates of both theories. The well, jointly sponsored by Sweden's power board and the Gas Research Institute of the US, lies north of Stockholm in a meteorite impact crater called the Siljan Ring. Gold suggested that the well be drilled here for several reasons. First, the Siljan Ring lies on a granite shield from which most overlying sedimentary rock has been stripped away by Ice Age glaciers, thus making it unlikely that gas found here would be of biological origin.

Second, the impact of the meteorite millions of years ago crushed the granite below, providing cracks and fissures that would allow the abiogenic gas to migrate upward. Seismic data had indicated that there are such porous zones deep in the granite. They also showed that there is a series of dense layers that could be cap rocks sealing reservoirs of gas and oil.

Third, traces of oil and gas had already been found in the area. Tar seeping from the granite had been used by the Vikings to seal their ships long ago, and lakes in the Siljan Ring sometimes bubble up methane. Both opponents and supporters of Gold's abiogenic theory agree that the Siljan Ring is one good place to test it.

Drilling began in 1986 and has been suspended as of September, 1987, until additional funding can be found. In February, 1987, at a depth of nearly 20,000 feet, the drill struck a very porous region, supporting Gold's contention that porous areas can exist deep in the Earth. While no great reservoirs of methane have yet been found, it is still unclear whether the traces that have been collected are abiogenic or biological in origin.

If a large reservoir of natural gas is found in the Siljan Ring, it could radically change the world's energy picture in many ways. It would enable us to use natural gas to meet more of our energy needs, with beneficial results for the environment. Countries that were believed to contain no reserves of biological gas might well contain abiogenic deposits, for no longer would prospectors need to find both a source rock and a cap, as well as the reservoir. Any capped porous region, even without sediments, would now be a potential reservoir. This would be particularly good news for poorer nations in areas like East Africa, where governments can ill afford the huge cost of importing oil. The impact might be felt politically as well as economically in many parts of the world, as the countries that are now petroleum-rich lose some of their power and influence to countries with newly-discovered gas reserves.

But if they don't strike gas in the Siljan Ring, what then? Even Gold's staunchest opponents admit that it wouldn't conclusively prove him wrong. After all, they've drilled their share of dry holes, too, many of them in very promising sites.

More important, though, than whether or not they find gas in the Siljan Ring, is the fact that they are continuing to look for other sites to test the theory. There are two reasons for this importance. First, it seems that we have been erroneously predicting the end of our oil and gas supplies for many years now. We have yet to run out. As Wallace Pratt wrote in 1952 in the *Bulletin of the American Association of Petroleum Geologists:*

> Where oil is first found, in the final analysis, is in the minds of men. When no man any longer believes more oil is left to be found, no more oil fields will be discovered, but so long as a single oil-finder remains with a mental vision of a new oil field to cherish, along with the freedom and incentive to explore, just so long new oil fields may continue to be discovered.

And, second, sometimes scientists interpret the same facts differently. If they didn't follow up their ideas, where would we be then? Still trying to make bees out of dead bulls and branches, no doubt.

Siljan Ring Site

Questions for Discussion

1. If a large methane reservoir is found in the Siljan Ring, do you think that the petroleum geologists who oppose the abiogenic theory will change their minds? Why or why not?

2. If you were an investor in the Siljan Ring drilling project and they never found appreciable amounts of methane, would you feel that your money had been wasted? Why or why not?

3. Some people take the statistic for proved natural gas reserves for a given year and divide it by the latest year's natural gas consumption to find the number of years of natural gas that we have "left." Why is this not an accurate statistic? (See the Appendix, Section IX.)

4. The article states that the impact of vast reserves of natural gas in formerly energy-poor countries "might be felt politically as well as economically in many parts of the world, as traditional spheres of influence and power change." What specific political changes might take place?

Questions for Review

1. Explain in steps how gas and oil are formed according to the biological theory; then do the same for the abiogenic theory.

2. What is **kerogen?**

3. Differentiate among the three kinds of rock listed below:
   source rock
   reservoir rock
   cap rock

4. List four ways in which "new" methane can be made.

5. Divide your paper vertically into two halves. On the left side, write down the three main pieces of evidence given to support Thomas Gold's abiogenic theory. On the right side, across from each statement, write how supporters of the biological theory would respond to it.

6. List three reasons why Gold has suggested the Siljan Ring as a good place to drill for abiogenic gas.

7. By yourself or together with another student, write down all the ways you can think of that our lives would change if next year a huge reservoir and abiogenic natural gas is found in the Siljan Ring.

Answers to Questions for Review

1. **Biological theory**—carbon dioxide→plants→gas/oil
   Abiogenic theory—carbonaceous chondrites→hydrocarbons→gas/oil
2. **Kerogen** is a tar-like substance that is the precursor to oil and gas in a source rock.
3. **Source rock** is the sedimentary rock in which oil and gas are formed. Once formed, they move into porous *reservoir rock*, where they will be trapped if this rock is covered by dense *cap rock*.
4. —kelp and water hyacinths
   —decaying garbage
   —cow manure
   —chicken feces
   —sewage
5. **Gold's Abiogenic Theory**
   1) Carbon is present on other planets (Jupiter, Saturn) and on meteorites as hydrocarbons, not as carbon dioxide.
   2) Oil and gas are found near fault and rift zones, places where they can migrate from deep in the Earth.
   3) The same ratios of trace elements are found in reservoirs of natural gas over large areas.

   Biological Theory Reponse
   1) Carbon on Earth is mostly in the form of carbon dioxide.
   2) The shifting of rock layers provides good cap rocks for oil and gas deposits.
   3) The trace elements have crept into these reservoirs at constant rates.
6. 1) Evidence of oil and gas has already been found in the area.
   2) The area has little/no sedimentary rock that could be the source of biological gas and oil.
   3) The impact of the meteorite made cracks that would allow deep-earth gas to migrate upward.
7. Answers will vary.

5. Videotape Activities Introduction

The two pages that follow include two sets of questions to accompany the videotape, "Theories and Conflict: The Origin of Natural Gas." Students may complete the "Viewing Guide" handout while they watch the tape; because the questions are numerous, you may want to review them first, or stagger them among students (assigning even/odd, for example).

Alternatively, students could divide a piece of paper into two columns and write "Biological Theory" at the top of one column, and "Abiogenic Theory" at the top of the other. They would then jot down supporting facts for each theory from the videotape while they watch. The "Viewing Guide" questions could then be answered after the tape. The "Questions for Discussion" are designed to be used after the viewing of the tape.

If you are using the videotape and questions without any other parts of the materials, you may wish to review with your students the facts about natural gas found in Section III.

The viewing time for the videotape is 21:16. The "Viewing Guide" questions follow the order of the tape. The answers to those questions appear on p. 14.

Questions for Discussion

1. Both abiogenic and biological theories of the origin of petroleum existed decades ago. Why did the biological theory gain favor?
2. In the laboratory, if you put source rocks under high pressures and temperatures, material like oil is produced. Does this prove that oil comes from the source rock? How does Dr. Gold explain these results?
3. How does Dr. Gold explain the existence of substances that are found in living organisms (cholesterol, for example) in petroleum? How do you think he might explain the fossils found in source rock?
4. There is one point upon which Dr. Mankin and Dr. Gold whole-heartedly agree. What is it?
5. Do *you* think it is important that we continue to explore both theories? Why or why not?
6. Why did Dr. Gold choose to drill at a site in Sweden where there are no biological sediments?
7. The first well drilled in the Siljan Ring in Sweden yielded only traces of methane. Does this prove that there is only a small amount of methane there? Why or why not?
8. How would wide acceptance of Dr. Gold's theory change the way we prospect for gas?
9. What is one political/economic effect that a large find of abiogenic gas might have?

Answers—Discussion Questions

1. Using the biological theory, petroleum prospectors were very successful.
2. No, it doesn't. Dr. Gold believes that it simply shows that oil exists there, but doesn't tell us whether it formed in those rocks or migrated to them from deep in the Earth.
3. He believes that living organisms, like bacteria we know of now that feed on oil, may have been attracted to the oil as a food source. He might propose that the fossils in source rocks are of organisms that came to feed on oil already there.
4. They agree that it is important to keep the question open and to continue to search for evidence of both theories.
5. Answers will vary.
6. The impact of the meteorite there crushed granite, making a perfect "reservoir rock," and also caused fissures that could allow deep gas to migrate upward. Also, because there was no sedimentary rock there, any methane would have to be abiogenic in origin.
7. No, it does not. Petroleum geologists often have to drill several wells before they hit "pay dirt."
8. We would look for it in places that we don't look now—places that may not have sedimentary source rocks.
9. Answers will vary.

Viewing Guide for "Theories and Conflict: The Origin of Natural Gas"

1. What are two ways in which we use natural gas?

2. What fraction of the energy needs in the US is met by natural gas?

3. The rock that traps gas and oil is called _____ rock.

4. According to most geologists, what forms natural gas and oil?

5. In the laboratory, when source rocks are put under high pressures and temperatures, _____ result.

6. If you examine source rocks under the microscope, what do you see?

7. According to Dr. Thomas Gold, from where do hydrocarbons come?

8. Is Dr. Gold's idea new?

9. Methane that could not be biological is found on the planets _____ and _____, and in _____.

10. The substance in many marine organisms that is very much like a substance found in oil is _____.
Is this the only such substance?

11. How do abiogenic and biological methane differ chemically?

12. Does laboratory "weighing" of methane indicate that most is biological or abiogenic?

13. How deep was the well drilled in the Soviet Union?

Did they find hydrocarbons there?

14. What was found in the Siljan Ring well?

15. Did this find convince others to believe in the abiogenic theory?

16. Why does Dr. Gold feel that his "kooky" theory is less accepted than the conventional one?

Answers—Viewing Guide Questions

1. Home heat, cooking, industry.
2. ¼
3. Reservoir rock.
4. Dead aquatic organisms buried under layers of rock.
5. Oil-like hydrocarbons.
6. Tiny fossils.
7. Deep in the earth, below biological sediments.
8. No.
9. Jupiter; Saturn; deep sea vents.
10. Cholesterol. No.
11. Biogenic gas has more C-12; abiogenic gas has more C-13.
12. Biological (high in C-12).
13. 36,000 ft. Yes, they found hydrocarbons.
14. Traces of abiogenic methane.
15. No. There wasn't much methane found.
16. Much more research has been done on the biological theory.

6. Critical Thinking Activities

Below are two different activities that will make students examine closely and think critically about what they have just read and seen.

1. **Role-Play Activity**—The use of a role-play can be effective for several reasons:

- It gives the students a stake in the issue.
- It gives them an opportunity to hone their negotiation and critical thinking skills.
- It provides students with a better idea of the real-life impact of this controversy, which exists most dramatically at petroleum geology conferences, but with most impact in the board rooms of gas companies making decisions about spending research money.
- All students are active participants in the activity.

Guidelines

1. Make enough copies of the activity sheet (following pages) so that each student will have one. Label ⅕ of the copies with an "A," ⅕ with a "B," and so on, through "E." These letters tell students which characters they will play. Then put the sheets in sets of five, each set including one sheet of each letter.
2. Divide the students into groups of five and distribute the sheets. If the number of students does not come out evenly, you may add or subtract a board member (C, D, or E) from one or more groups.
3. Go over the activity sheet with the students to be sure that they understand what they are to do. You may want to give them a definite format for the proposal. If they are to be evaluated on their work, tell them how it will be done.
4. Once all the final proposals have been handed in, put the results on the board in the form of a chart. Then, using the following procedure, find out the "results." You will need 30 small slips of paper; ten for each drilling location with each slip representing one well in that location.

   A. For the Horn Rim Valley, mark six of the ten slips with a red dot; put the slips into a hat or bowl and have a student draw one. If the slip drawn has a red dot on it, any group that chose to drill here made $12 million (expenses plus $2 million profit). If the slip is blank, no gas was found here and the groups who drilled lost their $10 million.
   B. For the Sunset Plain, repeat the procedure used in Part A, but this time mark only three of the ten slips with a red dot. A successful well will earn the company $20 million (expenses plus $5 million profit). A dry hole will cost the company the $15 million used to drill it.
   C. Use the same procedure for the Bowl Crater, but make only two of the slips with red dots. A successful well will earn the company $25 million (expenses plus $10 million profit) while a dry well will cost the company $15 million as in the Sunset Plain site. (B)

Total the financial "score" for each group. You may want to discuss what these sources represent.

2. **Debate**—Instead of doing a role-play, you could set up a debate on the controversy of biological *vs.* abiogenic natural gas. For this you may want to allow time for library research and interviews. People from outside the school could be brought in to act as judges for the debate.

Biological vs. Abiogenic Gas: How Should Prospecting Money Be Spent?

Objective: The objective of this activity is to help you to understand how science and business interact.

The Situation: Below is a list of facts that have been developed for this exercise. Though some may have parallels in real life, they represent a hypothetical situation.

- All of the characters involved work for American Natural Gas, a gas exploration company in the Midwest. Because last winter was unusually warm, the company was not profitable and must carefully watch its budget in the coming year. A large discovery of natural gas would help the company immensely.
- Funding decisions for the company are made by the 3-member Board of Directors. They usually commit ¼ of the company's total budget to exploration. This year's total budget is $100 million, so $25 million has been earmarked for exploration and drilling.
- In past years, the company's petroleum geologists have put together one proposal on how to spend the exploration portion of the budget. They have then presented the proposal to the Board of Directors for approval.
- This year, the petroleum geologists have been unable to agree on how to spend their part of the budget. There are three exploration areas under consideration:

  1) **The Horn Rim Valley**—Previous wells in this valley have been producing natural gas and oil for over ten years. There are still a few areas in the valley that haven't been drilled. Chances are slim that drilling here will yield a large reserve of gas, but any company that drills here should be able to recover its costs and make a small profit. Exploration here would cost $10 million.

  2) **The Sunset Plain**—A survey of the geology of this area shows evidence that it was once a riverbed. That riverbed is now buried under thousands of feet of rock. Geologists have suspected that natural gas might lie in this area, but have not been able to confirm it. Because of the geology in this area, exploration here would be very costly. The reserves could, however, be quite large and very profitable. Exploration here would cost $15 million.

  3) **The Bowl Crater**—There is no evidence to show that this area once held a body of water; in fact, there is little sedimentary rock here at all. The granite in the area is porous deep down due to the impact of a meteorite millions of years ago, but some of the shallower layers of rock are less porous. This site would only be an excellent prospect if the abiogenic theory is true; if it is not, drilling here would be a costly bust. Exploration here would cost $15 million.

The Task

Among you are two petroleum geologists and three board members. You must decide how ANG's prospecting budget ($25 million) will be spent, using the following process:

1. The two petroleum geologists (A and B) will each write a proposal that tells how much money should go to drilling in each of the three areas described above. They should both be ready to defend their choices with scientific evidence.

2. Each of the petroleum geologists should present his/her proposal to the Board of Directors, and should explain the evidence used to come up with the proposal.

3. After the presentation of the two proposals, the board members may question the petroleum geologists and discuss their proposals.

4. One of the board members may suggest at any time that they accept one of the proposals. If the other two board members agree, that proposal will be the one put into action. The geologists do not need to agree for the proposal to be accepted.

5. When a proposal is agreed upon, the supporting evidence is written up, attached to the proposal, and handed in to the teacher.

The Characters:

A. You are a petroleum geologist who has been with ANG for twenty-five years. You are good at what you do, and usually provide the company with a steady profit from exploration. You strongly support the "fossil fuel" theory and would like to find a "big one" before you retire. This would enhance your reputation and enable you to obtain lucrative consulting fees in the future.

B. You are a petroleum geologist who has just finished your Ph.D.; you have been working with ANG for about nine months. You are anxious to establish your reputation in the field, and have become convinced that the abiogenic theory is worth considering. You feel that if ANG does not explore this theory, it will fall behind other gas companies who may prospect in the areas where abiogenic gas might be found. However, you don't want to blow this opportunity and end your career, you need to be successful.

C, D, and E. You are members of the Board of Directors of ANG. You have two primary concerns; they are to:

1) not go over the budget unless the potential return is great enough to justify the expenditures, and
2) make the most profitable decision.

7. Worksheet—Origin of Natural Gas

Name_____

This worksheet will help you to put together the information you have learned in this unit.

A. **Matching.** Match the words on the left with their definitions on the right.

A. methane
B. seismic
C. hydrocarbon
D. kerogen
E. chondrite
F. abiogenic
G. biological
H. source rock
I. reservoir rock
J. ethane
K. cap rock

_____1. Any substance made only of carbon and hydrogen atoms.
_____2. Porous rock that can hold migrating gas and oil.
_____3. The tar-like substance from which gas and oil form.
_____4. The chemical name for natural gas.
_____5. Sedimentary rock that, under high temperature and pressure, yields oil-like substances.
_____6. Coming from living things.
_____7. Dense rock that will not allow migrating oil and gas to pass.
_____8. Coming from non-living things.

B. Draw a diagram of the biological theory of the origin of natural gas, beginning with carbon dioxide and ending with methane.

C. Explain briefly where natural gas comes from according to Dr. Thomas Gold's abiogenic theory.

D. Below are listed phrases associated with one of the two theories of the origin of natural gas that have been discussed. Choose one phrase that supports the **biological** theory and explain in detail how it does so; then choose one that supports the **abiogenic** theory and explain that.

fossils
deep sea vents
planetary methane
"cooked" source rocks
helium patterns in gas reservoirs
cholesterol/cholestane

E. "The money being used to investigate Dr. Gold's abiogenic theory is being wasted; it could be better spent exploring for gas using the 'tried and true' biological theory of its origin."

Do you agree or disagree with this statement? Give two reasons for your response.

F. What chance in ten would you give Dr. Gold to succeed in his project? Explain.

Worksheet Answers

A. **Matching.**
1. C 2. I 3. D 4. A 5. H
6. G 7. K 8. F

B. CO_2 plants animals
buried under rock gas + oil

C. According to Dr. Gold's abiogenic theory, hydrocarbons (including methane) were a part of the forming Earth, and are now making their way out through cracks in the Earth's crust.

D. Fossils—(biological theory)—When thin slices of source rock are examined under a microscope, fossils can be seen. This would seem to indicate that these fossilized organisms were the source of the gas and oil formed in the rock.

Deep sea vents—(abiogenic theory)—Gases, including methane, have been discovered venting deep in the Pacific Ocean. The source of these gases is not biological, as there are no biological sediments that could have formed them.

Planetary methane—(abiogenic theory)—Methane is found in the atmospheres of other planets, but we do not believe that these planets have ever sustained life. This would indicate that living organisms are not the only route to methane.

"Cooked" source rocks—(biological theory)—When source rocks are subjected to high heat and pressure in the laboratory, oil-like substances result, indicating that the organic material in the rock produces, under the right conditions, petroleum.

Helium patterns—(abiogenic theory)—The fraction of helium found in different methane reservoirs in the same large area is often the same, indicating that the methane in each of these reservoirs came from the same deep source, not from several different source rocks, as supporters of the biological theory would suggest.

Cholesterol/cholestane—(biological theory)—Substances that are very similar to substances found in living organisms are often found in source rocks. An example of this is cholestane, which is found in source rocks and is very similar to the cholesterol found in living marine organisms.

E. Answers to this question will vary, although it is hoped that students will see the value in continuing to explore both theories, whatever the outcome may be.

F. Answers will vary.

8. Sources

The following materials can be consulted for further information:

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"Prospecting." *Scientific American.* August, 1985. pp. 64-65.

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Riva, Joseph P., Jr. *World Petroleum Resources and Reserves.* Boulder, CO: Westview Press, 1983.

For information on the supply of gas, contact:

American Gas Association, 1515 Wilson Blvd., Arlington, VA 22209

Gas Research Institute, 8600 West Bryn Mawr Ave., Chicago, IL 60631

Potential Gas Agency, Colorado School of Mines, Golden, CO 80401

United States Department of Energy, National Energy Information Center, EI-231, Forrestal Building, Washington, DC 20585

9. Appendix: Natural Gas Supply
How Can We Estimate Supplies for the Future?

Many scientists believe that our planet holds vast reserves of natural gas that will help meet our nation's and the world's energy needs for hundreds of years. Just how much natural gas is available to meet those needs is a critical question to answer as we plan our country's economic and environmental future. How can we be so sure that natural gas will be abundantly available for future generations? Here's how the experts measure natural gas reserves.

The amount of gas energy may be measured by several means, one of which is the British thermal unit (Btu). One Btu is enough gas to heat one pound of water one degree Fahrenheit under standard pressure. Because a single Btu is a small unit, gas supply on a nationwide basis is discussed in quadrillion Btu (quads). A quad is 1,000,000,000,000,000 Btu.

In 1987 the United States produced 16.7 quads of natural gas. About 0.3 of those quads were produced in Alaska and 16.4 quads came from the lower-48 states. Additional supply came from Canadian imports and supplemental sources such as synthetic natural gas (SNG), for a total of 17.7 quads used. Canadian natural gas reserves are extensive and the amount we import from Canada is expected to grow over the next decade. At present we do not have pipelines from Alaska to the lower-48 states because they are expensive to construct, and we have not needed Alaska's large supply as yet.

In looking to the long-term future of natural gas supply, scientists must consider three categories of sources. The first type is proved reserves (see p. 12 of unit) which are reservoirs of gas already known to exist. This is the most certain supply, and the lower-48 states have approximately 164 quads of proved reserves. Each year, new natural gas fields are discovered and are added to our proved reserves. This means that we continue to build up our inventory of proved reserves at the same time we are using them.

Potential, or "inferred," reserves are those that can be expected to lie in areas where rock conditions have been determined to be right for natural gas reservoirs to exist. Estimated potential reserves for the lower-48 states at present are 640 quads, in addition to the 164 quads of proved reserves, for a total of 804 quads.

When experts take these two types of sources into account, they generally agree that we have about a 50-year supply of natural gas, at present consumption rates and at current prices. As technology develops and new methods of discovering natural gas are proven successful, our supply of natural gas from conventional sources will continue to increase.

The third category of sources for natural gas, nonconventional sources, could be the most plentiful of all and could possibly extend our supply of natural gas for several hundred years. Although methods for production of gas from many nonconventional sources remains in experimental stages today, the vast potential these sources represent justifies a continued effort to develop them.

The most widely used of the nonconventional sources at this time is the **landfill**. Here methane gas is formed by organic waste decaying in municipal landfills. Wells are drilled into each fill to drain gas out and it is vacuumed out into a purification system. Today there are 13 working landfill gas production sites and seven more are under construction.

Another nonconventional option is **biomass and waste**. The term "biomass" in this report refers to plants grown specifically for the production of energy. "Waste" refers to the organic byproducts of animal and vegetable matter which was not grown specifically for energy production. The production of methane from biomass and waste involves the use of anaerobic digestion or thermochemical conversion to change solid or liquid organic material into a gaseous form which must be processed to produce high-Btu pipeline quality gas.

Coal gasification employs a chemical process to make coal into methane gas. Coal is especially plentiful in the United States where a 300-year supply exists according to recent estimates. When coal cannot be reached in the ground, it can be gasified and brought out in that form. An estimated 1.8 trillion tons of presently unrecoverable coal could be converted to methane gas; even 5 percent of that amount would be enough to increase our proved supply of natural gas by two and one-half times.

Oil-Shale is a fine-grained sedimentary rock containing an organic material called kerogin which produces oil and gas when it is heated. Shale deposits in the Western and Eastern U.S. may produce a great deal of natural gas once a process of retrieving it can be perfected.

Hydrates are ice-like compounds in which methane gas becomes trapped in a crystalline structure. Hydrates exist in colder areas like permafrost land masses and deep in the sea. At this time there is no economically feasible method of extracting this methane from the hydrates; however, research continues because the estimated world supply of methane-hydrates is approximately 6.9 million quads. Production of even a small percentage of the known supply would add tremendously to our reserves.

All of the above estimates do not even consider the possible supply from abiogenic sources as discussed in this unit, since most geologists consider them too speculative to be

considered in reserve estimates.

As we move into the future, scientists will continue to develop new technologies for production of gas from a variety of nonconventional and as yet unproved sources. As these new technologies make vast new sources of gas supply accessible, natural gas will play an expanding role in the nation's energy future.

Sources:

An Assessment of the Natural Gas Resource Base of the United States. U.S. Dept. of Energy. May 1988.

The Gas Energy Supply Outlook 1987-2010. American Gas Association. October 1987.

The Future of Natural Gas in the United States. American Gas Association. April 1988.

10. Teacher Response Form

Theories and Conflict: The Origins of Natural Gas

To assist us in continuing to provide useful materials to you, we would appreciate your taking the time to complete and return this brief questionnaire.

Name_____ School_____

Address_____ City/State/Zip_____

Grade level/Subject in which used_____

How would you rate this unit? Excellent ____ Good ____ Fair ____ Poor ____

Would you recommend the material to other teachers? _____ Why or why not?_____

Which parts of the unit did you use? Introductory Activity _____ Fact Sheets _____ "The Origin of Natural Gas" articles _____ Video _____ Viewing Guide _____ Role Play/Debate Activity_____ Worksheet _____

Which part(s) of the unit did you like best?_____

Which part was least useful?_____

Was the material appropriate for the subject/grade level in which you used it? For what other subjects/grades would you recommend its use?

_____

Were the teacher's instructions helpful and adequate? _____ How might they be improved?_____

_____

Please note any suggestions for improving the unit._____

_____

_____

Return to: Manager, Educational Programs
American Gas Association
1515 Wilson Blvd.
Arlington, VA 22209

Thank you for your interest and cooperation.

11. Additional Materials

Among other materials available through your gas company or the American Gas Association are:

N00085 **Experiments: Properties of Gas and Heat Energy.** A book of experiments prepared on spirit duplicating masters for use in high school physics, chemistry or general science classes.

N00671 **Energy Reports.** A set of reports on topics related to natural gas or other energy issues. Includes topics such as conservation, safety, offshore drilling, non-conventional sources and the environment.

N00610 **Explore Your Future: Careers in the Natural Gas Industry.** A booklet for use in junior high classes or career days; contains a brief overview of the gas industry, 19 job profiles of typical gas industry positions, and interviews with a number of gas industry employees.

N50010 **The Balancing Act: How Utility Rates are Decided.** A mini-unit to help high school students and teachers understand how utility (gas, electric, telephone, water) rates are determined by state regulatory authorities. Appropriate for 11th and 12th grade classes in government, economics or consumer education, or for a variety of adult groups. Contact your local utility for availability in your area.

N00450 **Natural Gas Teaching Materials.** Catalog listing educational materials available from the American Gas Association.

12. Glossary

- **Abiogenic**—adj., not of biological origin.
- **Aquatic**—adj., living in water.
- **Astrophysicist**—n., a scientist who studies a branch of astronomy dealing with the physical and chemical make-up of bodies in the universe.
- **Carbonaceous chondrite**—n., meteorite that contains hydrocarbons in rounded granules.
- **Fault**—n., a fracture in the earth's crust.
- **Hydrocarbon**—n., any compound made up only of carbon and hydrogen.
- **Isotope**—n., an atom of an element with a different mass.
- **Kerogen**—n., a tar-like substance that is a precursor to petroleum.
- **Mantle**—n., the section of the Earth between the core and the crust.
- **Nonporous**—adj., not having holes or pores.
- **Organic**—adj., coming from living things.
- **Oxidize**—v., to combine with oxygen.
- **Porous**—adj., having pores or holes, like a sponge.
- **Pulsar**—n., a source of pulsating radio waves in space.
- **Seismic**—adj., having to do with earthquakes or man-made earth tremors.
- **Steady-state Theory**—n., a theory of the universe that holds that there was not a beginning of the universe, that it has always been as it is now.
- **Trace element**—n., an element that is present in a very small amount in a substance.

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Order and Billing Dept.
1515 Wilson Blvd.
Arlington, VA 22209

Quantity desired: Complete kits (N55010)_____ Videos (N55011)_____ Lesson Plans (N55012)_____

Amount enclosed_____

Name_____

School or Company_____

School or Company Address_____

City_____ State_____ Zip_____

Gas Company serving school_____